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SCALABLE, SPACE EFFICIENT, HIGH DENSITY AUTOMATED LIBRARY

BACKGROUND OF THE INVENTION

5   **1.   Technical Field:**

The present invention relates to storage systems. More specifically, the present invention relates to systems for storing a plurality of components which may contain data.

10

2.   Description of Related Art:

The cost of occupying computer room floor space has become very expensive to maintain in today's cost-conscious, computer-intensive business environment.
15   Typical automated libraries often occupy large amounts of space and yet only contain a small portion of the installation's total data (the rest being stored in warehouses). Improvements in space efficiency are required to relieve the growing need to fit more powerful
20   computer equipment into a constrained area.

Today's large automated libraries are arranged in a way that requires a significant amount of dedicated space just to service the library. This space is, at least, as large as a normal sized adult and cannot be used for
25   storing tapes, drives, robots, etc. The larger the library, the more space is generally required to service the functions of the equipment.

Present automated library designs do not allow space consumption scalability, which would allow users to
30   adjust the size of the library according to their needs. Present library designs also have large individual units

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of configuration and do not allow much flexibility in their physical layout, reducing the efficiency with which available space can be used.

5   Therefore, an automated library design that is space efficient and allows scalability and flexibility in its layout would be desirable.

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SUMMARY OF THE INVENTION

The present invention provides removable-unit storage modules, which can be combined into a network.
5 The storage modules comprise storage cells arranged in a rule based structure or in an algorithmically controlled manner (e.g. series of rows and columns) which can be organized in a flat matrix configuration similar to x, y libraries today or in a curved or cylindrical matrix, and
10 robotic hands which move along tracks in order to retrieve objects from the storage cells. In one embodiment, the storage cells are used to contain data storage units.

Several modules can be combined into a network by
15 means of bridge tracks which connect the tracks of different modules, allowing the robotic hands to move between modules. The bridge tracks can be dynamically connected and disconnected from the modules, allowing the network configuration to change according to user needs.
20 The individual modules are mobile and can be transported to other locations and connected with other removable-unit storage networks.

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BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the
5   invention are set forth in the appended claims. The
invention itself, however, as well as a preferred mode of
use, further objectives and advantages thereof, will best
be understood by reference to the following detailed
description of an illustrative embodiment when read in
10   conjunction with the accompanying drawings, wherein:

Figure 1 depicts a pictorial representation of a
distributed data processing system is in which the
present invention may be implemented;

Figure 2 depicts a block diagram of a data
15   processing system which may be implemented as a server,
in accordance with the present invention;

Figure 3 depicts a block diagram of a data
processing system in which the present invention may be
implemented;

20   **Figure 4** depicts a perspective view pictorial
diagram illustrating four modules of a removable-unit
storage network in accordance with the present invention;

Figure 5 depicts a top view pictorial diagram
illustrating the same modules illustrated in **Figure 4**;

25   **Figure 6** depicts a schematic diagram illustrating a
single module of a removable-unit storage network in
accordance with the present invention;

Figure 7 depicts a schematic diagram illustrating
the top view of two modules of a removable-unit storage
30   network in accordance with the present invention;

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Figure 8 depicts a schematic diagram illustrating a single storage module with canted tracks in accordance with the present invention;

Figure 9 depicts a schematic diagram illustrating
5   the combination of modules with different geometric arrangements in accordance with the present invention;

Figures 10A-C depict schematic diagrams illustrating movable module arrays in accordance with the present invention;

10   **Figure 11** depicts a schematic diagram illustrating how the present invention can be applied to modules with different elevations; and

Figure 12 depicts a schematic diagram illustrating how the present invention can be combined with more
15   traditional rotating robotic retrieval systems.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

It must be noted at the outset that the methodology, technique, and means described are not limited to computer systems nor to the storage of computer data but are general in nature and apply in a broad spectrum of library and warehousing applications. The description that follows explains the use of these principles in the context of computer systems by way of illustration, and the preferred embodiment will describe their use in the context of libraries of removable storage units, whether the units be tape cartridges or complex units containing electronics.

With reference now to the figures, and in particular with reference to **Figure 1**, a pictorial representation of a distributed data processing system is depicted in which the present invention may be implemented.

Distributed data processing system **100** is a network of computers in which the present invention may be implemented. Distributed data processing system **100** contains network **102**, which is the medium used to provide communications links between various devices and computers connected within distributed data processing system **100**. Network **102** may include permanent connections, such as wire or fiber optic cables, or temporary connections made through telephone connections. In the depicted example, server **104** is connected to network **102**, along with storage unit **106**. In addition, clients **108**, **110** and **112** are also connected to network **102**. These clients, **108**, **110** and **112**, may be, for example, personal computers or network computers.

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For purposes of this application, a network computer
is any computer coupled to a network that receives a
program or other application from another computer
coupled to the network. In the depicted example, server

5   **104** provides data, such as boot files, operating system
images, data from databases or specific files used by
applications, and executable modules of applications, to
clients **108-112**. Clients **108**, **110** and **112** are clients to
server **104**. Distributed data processing system **100** may

10 include additional servers, clients, and other devices
not shown. Distributed data processing system **100** also
includes printers **114**, **116** and **118**. A client, such as
client **110**, may print directly to printer **114**. Clients
such as client **108** and client **112** do not have directly

15 attached printers. These clients may print to printer
116, which is attached to server **104**, or to printer **118**,
which is a network printer that does not require
connection to a computer for printing documents. Client
110, alternatively, may print to printer **116** or printer

20 **118**, depending on the printer type and the document
requirements.

In the depicted example, distributed data processing
system **100** is the Internet, with network **102** representing
a worldwide collection of networks and gateways that use

25 the TCP/IP suite of protocols to communicate with one
another. At the heart of the Internet is a backbone of
high-speed data communication lines between major nodes
or host computers consisting of thousands of commercial,
government, education, and other computer systems that

30 route data and messages. Of course, distributed data
processing system **100** also may be implemented as a number

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of different types of networks such as, for example, an intranet or a local area network.

Figure 1 is intended as an example and not as an architectural limitation for the processes of the present

5   invention.

Referring to **Figure 2**, a block diagram of a data processing system which may be implemented as a server, such as server **104** in **Figure 1**, is depicted in accordance with the present invention. Data processing system **200**

10   may be a symmetric multiprocessor (SMP) system including a plurality of processors **202** and **204** connected to system bus **206**. Alternatively, a single processor system may be employed. Also connected to system bus **206** is memory controller/cache **208**, which provides an interface to

15   local memory **209**. I/O bus bridge **210** is connected to system bus **206** and provides an interface to I/O bus **212**. Memory controller/cache **208** and I/O bus bridge **210** may be integrated as depicted.

Peripheral component interconnect (PCI) bus bridge

20   **214** connected to I/O bus **212** provides an interface to PCI local bus **216**. A number of modems **218-220** may be connected to PCI bus **216**. Typical PCI bus implementations will support a specific number (often in the range of two to seven) of PCI expansion slots or add-

25   in connectors. Communications links to network computers **108-112** in **Figure 1** may be provided through modem **218** and network adapter **220** connected to PCI local bus **216** through add-in boards.

Additional PCI bus bridges **222** and **224** provide

30   interfaces for additional PCI buses **226** and **228**, from

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which additional modems or network adapters may be
supported. In this manner, server **200** allows connections
to multiple network computers. A memory mapped graphics
adapter **230** and hard disk **232** may also be connected to

5   I/O bus **212** as depicted, either directly or indirectly.
Those of ordinary skill in the art will appreciate that
the hardware depicted in **Figure 2** may vary. For example,
other peripheral devices, such as optical disk drives and
the like, also may be used in addition to or in place of

10   the hardware depicted. The depicted example is not meant
to imply architectural limitations with respect to the
present invention.

    The data processing system depicted in **Figure 2** may
be, for example, an IBM RS/6000, a product of

15   International Business Machines Corporation in Armonk,
New York, running the Advanced Interactive Executive
(AIX) operating system.

    With reference now to **Figure 3**, a block diagram of a
data processing system in which the present invention may

20   be implemented is illustrated. Data processing system
300 is an example of a client computer. Data processing
system **300** employs a peripheral component interconnect
(PCI) local bus architecture. Although the depicted
example employs a PCI bus, other bus architectures, such

25   as Micro Channel and ISA, may be used. Processor **302** and
main memory **304** are connected to PCI local bus **306**
through PCI bridge **308**. PCI bridge **308** may also include
an integrated memory controller and cache memory for
processor **302**.

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Additional connections to PCI local bus **306** may be made through direct component interconnection or through add-in boards. In the depicted example, local area network (LAN) adapter **310**, SCSI host bus adapter **312**, and

5   expansion bus interface **314** are connected to PCI local bus **306** by direct component connection. In contrast, audio adapter **316**, graphics adapter **318**, and audio/video adapter (A/V) **319** are connected to PCI local bus **306** by add-in boards inserted into expansion slots. Expansion

10 bus interface **314** provides a connection for a keyboard and mouse adapter **320**, modem **322**, and additional memory **324**. In the depicted example, SCSI host bus adapter **312** provides a connection for hard disk drive **326**, tape drive **328**, CD-ROM drive **330**, and digital video disc read only

15 memory drive (DVD-ROM) **332**. Typical PCI local bus implementations will support three or four PCI expansion slots or add-in connectors.

An operating system runs on processor **302** and is used to coordinate and provide control of various

20 components within data processing system **300** in **Figure 3**. The operating system may be a commercially available operating system, such as AIX, which is available from International Business Machines Corporation. "AIX" is a trademark of International Business Machines Corporation.

25 An object oriented programming system, such as Java, may run in conjunction with the operating system, providing calls to the operating system from Java programs or applications executing on data processing system **300**. Instructions for the operating system, the object-

30 oriented operating system, and applications or programs

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are located on a storage device, such as hard disk drive **326**, and may be loaded into main memory **304** for execution by processor **302.**

Those of ordinary skill in the art will appreciate
5 that the hardware in **Figure 3** may vary depending on the implementation. For example, other peripheral devices, such as optical disk drives and the like, may be used in addition to or in place of the hardware depicted in **Figure 3.** The depicted example is not meant to imply
10 architectural limitations with respect to the present invention. For example, the processes of the present invention may be applied to multiprocessor data processing systems.

Referring now to **Figure 4**, a perspective view
15 pictorial diagram illustrating four modules of a removable-unit storage network is depicted in accordance with the present invention. Removable units can be individual units of media such as, for example, a tape cartridge, a magazine of cartridges, or more complex
20 units such as individual disk drives. **Figure 5** depicts a top view pictorial diagram illustrating the same modules illustrated in **Figure 4.** Each module **401-404** has several robotic hands **405** which are capable of retrieving object from storage cells **408** within the modules **401-404.** The
25 robotic hands move along rows of tracks **406** and can be moved between rows of tracks by means of an elevator mechanism **407.** As can be seen in **Figure 5**, all of the features described can be placed on both sides of the storage modules **401-404.** The modules **401-404** are
30 identical to each other and can be used separately or in

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combination (as will be explained below), according to the user's needs. It is this modular feature that gives the present invention much of its flexibility and adaptability to different requirements. Note that the

5   unused space is configured between modules **401** and **402** while the rest of the modules only have enough space to allow robotic hands to safely pass each other.

Referring to **Figure 6**, a schematic diagram illustrating a single module of a removable-unit storage

10   network is depicted in accordance with the present invention, and **Figure 7** depicts a schematic diagram illustrating the top view of the present invention. The module **600** has several robotic hands or "bots" **601** which are capable of retrieving individual units from within

15   module **600**. The units are contained in cells, represented by cell **604** in **Figures 6** and **7**. In the present example, the cells **604** are arranged in a series or row and columns, but they could be arranged in several other geometric arrangements (e.g. spirals, ellipses) or

20   combinations of arrangements. The general case is a rule-based structure that can be modified by moving the rails from one configuration to another. The total number of cells **604** within a module **600** can vary depending on factors such as the size of the module **600**

25   and the size of the cells **604** themselves, depending on what kind of unit is stored.

The types of units contained with the cells **604** can include, for example, magnetic tapes, CD-ROMs, DVD-ROMs, hard drives, or any other type of data storage unit.

30   However, it should be pointed out that the concept behind

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the present invention could also be applied to any type
of inventory the user may wish to store in the cells **604**.

In order to retrieve units from the cells **604**, the
bots **601** move under their own power along several rows of
5   tracks **602**. A vertical elevator mechanism **603** can be
used to move bots **601** from one level of tracks **602** to
another. This elevator mechanism can work by hydraulics
or cables to pull bots **601** up or down and can be located
at either end of the module **600** or anywhere along its
10   length. The features of module **600** also exist on the
opposite side of the module **600** (not shown) and can be
used as an extension of the illustrated side, allowing
the bot to circle the entire module at one track level.

An alternative embodiment of module **600**, module **800**
15   shown in **Figure 8**, allows the bots **601** to spiral around
the module on canted tracks **802** to the top and then use
an elevator **603** to reach the bottom again. Alternatively,
the embodiment in module **800** would allow the bots **601** to
spiral around the module **800** to the top using a subset of
20   the tracks **802** and then reverse direction and spiral back
to the bottom using another subset of the tracks **802**,
then reversing direction again, repeating the process.

Referring to **Figure 9**, a schematic diagram
illustrating the combination of modules with different
25   geometric arrangements is depicted in accordance with the
present invention. **Figure 9** is merely one of several
possible examples of combining modules with different
geometric configurations. In this example, a module with
horizontal tracks, such as module **600**, and one with
30   canted tracks, such as module **800**, are connected so that

the bots **601** move horizontally across module **600**, spiral up module **800** and then move back across module **600** at the next higher level.

To reduce interference between bots **601**, the module

5   **600** can be set up so that different rows of bots **601** move in different directions. One reason for having opposite unidirection motion on different rows is to reduce the length of motion from data storage unit location to the location of the read/write station. Unidirectional

10 motion can also be used when modules are densely packed together, or if a spiral track design is used.

Once a bot **601** has retrieved a unit from a cell **604**, it can then carry the unit to the desired location, such as a drive or a read/write station, or to a bay with I/O

15 connections and plug it in. The drives, read/write stations, and I/O ports can be located at one or both ends of the module **600**, or interspersed along its length.

The storage module **600** can also have an external skin and frame to prevent users from being snagged by

20 moving bots **601**.

The process of retrieving units and placing them in the proper places requires a mechanism to do routing and bridging of the storage housing, mating of media to drives, mating of drives to read/write stations, and

25 determination of what components can read or write to which storage units. These functions are extant in all network systems and are known in the art.

The storage configuration used within a module **600** can be attribute or policy based. An example of an

30 attribute based configuration is a Redundant Array of Independent Tapes (RAIT), in which a group of tapes is

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configured to appear as one tape to the user. For example, when the user chooses to write to tape A, the data is actually written to eight tapes and three parity tapes, so that any three tapes can be damaged or lost but

5   the user can still retrieve all of the data.

A policy based configuration would reflect a decision made at a business level, which is then communicated to an operational level. An example of a decision at the business level would be to have something

10   sent on payday. On the operational level, the changes to the configuration would be made as necessary to accomplish the business goal.

Many of the advantages of the present invention relate to the different ways in which several modules **600**

15   can be networked together and separated, according to the needs of users. In addition, the networking of the modules **600** can be dynamic and change configuration as needs change during specified time periods.

Referring now to **Figure 7**, a schematic diagram

20   illustrating the top view of two modules of a removable-unit storage network is depicted in accordance with the present invention. The modules **701** and **702** in **Figure 7** are identical in structure and function to module **600** in **Figure 6**. **Figure 7** illustrates several examples of how

25   separate modules **701** and **702** can be networked together. However, the examples illustrated in **Figure 7** are by no means exhaustive, as will be explained below.

To allow the bots **601** to move from one side of a module **701** to another, convex bridges **605** can be placed

30   at one or both ends of the module **701**. The bridges **605** would connect with the horizontal tracks **602** along which

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the bots **601** move. The bridges **605** can be moved
dynamically as needed in and out from the module **701**,
depending on where the bots **601** need to go. Bridges **605**
on different rows can be moved independently of each
5   other or together as a column.

To move bots **601** from one module **701** to another
module **702**, either a convex bridge **606** or concave bridge
607 can be used. Bridge **606** functions similarly to
bridge **605** and is used to move a bot **601** between the far
10 sides of two modules **701** and **702**, as illustrated in
Figure 7. Bridge **606** could also be used if additional
modules are placed between modules **701** and **702**, allowing
a bot **601** to move directly from one far end of a battery
of modules to another. Bridge **607** is used to move a bot
15 **601** between facing sides of different modules **701** and
702, as shown in **Figure 7**.

The bridges **605-607** depicted in **Figure 7** are 180
degrees, allowing bots **601** to move between module sides
that are parallel to each other. However, in the case
20 where modules **701** and **702** are placed perpendicular to
each other, a 90-degree connecting bridge (not shown)
would be used.

Bridging can be algorithmically controlled (e.g.
time based). For example, during a backup window of the
25 day, the user may want one large network modules, but
during the transaction window of the day, the user may
want several smaller networks available. Bridging can
also be policy controlled, establishing general goals for
the network, with the details to be implemented at the
30 algorithmic level.

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Control of bridging can also serve as a security measure within a removable-medium storage network. Specific users may be given access to specific modules within the network. As a result, bridging between
5   certain modules, and hence access to those modules, may only be accomplished from certain clients **300** within a computer network **100**.

The active elements of a module (including such things as bots in motion and media in drive being read or
10   written) can continue to be active while the module is moved from association with one set of modules in an array to association with another module. This association can be accomplished via moving bridges or via actually moving the modules.

15   Those skilled in the art will appreciate how the different bridge designs **605-607** can be used to various network configurations. In addition, the ability to connect and disconnect the bridges **605-607** allows the network configuration to change dynamically, according to
20   changing needs. Not only do bridges, such as bridges **605-607**, allow a given bot **601** to access units from different modules **701** and **702**, but they also create new paths for bots **601** to move units from one module **701** to another **702**.

25   An important feature necessary for bridging different modules in a removable-medium storage network is meta data. Meta data is an inventory of resources available to a module at any given time and is maintained on a micro basis (short time periods). Examples of meta
30   data include what data storage devices are located within a module, where the storage units are located, and how

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many bots are now on the module and where they are
located, which can change every few fractions of a second
as bots move from one module to another. When bridging
it is very important to connect a bridge and then merge
5 and integrate the meta data from the two or more modules
connected. When a bridge is removed, the meta data is
uncoupled. Meta data can be stored in NV-RAM, on a hard
drive, or any other type of non-volatile memory storage
within the modules, which can hold its memory without
10 power.

        An additional feature of the present invention,
which gives it even greater versatility, is the ability
to physically move a module from one location to another.
Current library structures have rigid placement of
15 storage modules, which include unused space (e.g.
necessary for maintenance and repair operations by a
human operator). The present invention allows for this
previously empty space to be filled with storage modules
and for needed empty space to be realized when requested,
20 by moving a module(s). The previous discussion on
bridges requires that the bridges be adaptable to the
range of motion of the modules by, for example, extenders
or by flexing.

        Referring to **Figures 10A-C**, schematic diagrams
25 illustrating movable module arrays are depicted in
accordance with the present invention. The ranges of
motion for the modules include some that keep the modules
in service and part of the overall processing of the
array **1000** of modules while being moved, as illustrated
30 in **Figure 10A**. In **Figure 10A**, the end modules **1001** and
1006 are fixed, and the middle modules **1002-1005** are

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movable. Space for human intervention (e.g. repair) can be realized between any pair of modules by laterally moving one of the middle modules **1002-1005**. In **Figure 10A**, module **1005** is moved laterally. In another

5   embodiment, some movement of a module would allow the module to remain in service but require that it be disconnected from the rest of the array **1000**, as shown in **Figure 10B**. In **Figure 10B**, the module **1003** is moved perpendicular (horizontally or vertically) to the array

10   **1000** in order to create space for human intervention. Yet another embodiment, part of the range of motion would allow a module **1004** to be removed from one array **1000** into another **2000**, as illustrated in **Figure 10C**.

Figure 11 depicts a schematic diagram illustrating

15   how the present invention can be applied to modules with different elevations. Bot tracks **1103** are used as connecting bridges to connect modules **1101** and **1102**, which are at uneven elevations.

Figure 12 depicts a schematic diagram illustrating

20   how the present invention can be combined with more traditional rotating robotic retrieval systems. Separate rotational libraries **1201** and **1202** can be connected together by bridge tracks **1204**, allowing bots **1203** to move between libraries **1201** and **1202**. In this manner,

25   the ends of modules can function as cartridge access ports.

If a module has self-locomotion, it could be driven like a radio-controlled car in two different ways. The first method is arrhythmic, in which an onboard or remote

30   system knows the floor layout and directs the module to

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the correct location. The second option is for a person
to manually control the module with a remote control.
Stability concerns when driving a module are easily
solved by means of ballast in the bottom, a wider base,
5   or transporting the module on a cart with a wide base.
In addition to self-locomotion, modules can be loaded
into a transport, shipped to anywhere in the world, and
then networked with a new set of modules in the new
location. When transporting modules between different
10   locations, the ability to integrate and decouple meta
data between modules is critical.

     It is important to note that while the present
invention has been described in the context of a fully
functioning data processing system, those of ordinary
15   skill in the art will appreciate that the processes of
the present invention are capable of being distributed in
the form of a computer readable medium of instructions
and a variety of forms and that the present invention
applies equally regardless of the particular type of
20   signal bearing media actually used to carry out the
distribution. Examples of computer readable media
include recordable-type media, such as a floppy disk, a
hard disk drive, a RAM, CD-ROMs, DVD-ROMs, and
transmission-type media, such as digital and analog
25   communications links, wired or wireless communications
links using transmission forms, such as, for example,
radio frequency and light wave transmissions. The
computer readable media may take the form of coded
formats that are decoded for actual use in a particular
30   data processing system.

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The description of the present invention has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and

5 variations will be apparent to those of ordinary skill in the art. The embodiment was chosen and described in order to best explain the principles of the invention, the practical application, and to enable others of ordinary skill in the art to understand the invention for

10 various embodiments with various modifications as are suited to the particular use contemplated.